FORM PTO-1390 (Modified) (REV 11-2000) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER	U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR
220040US2PCT	10/069517

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/FR00/02468	07 SEPTEMBER 2000	08 SEPTEMBER 1999

TITLE OF INVENTION

CREATION OF AN ELECTRICALLY CONDUCTING BOINDING BETWEEN TWO SEMI-CONDUCTOR

APPLICANT(S) FOR DO/EO/US

Claude JAUSSAUD, et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include itens (5), (6), (9) and (24) indicated below.
4. ☒ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   a. ☐ is attached hereto (required only if not communicated by the International Bureau).
   b. ☒ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☒ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. ☒ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).
11. ☐ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☒ A copy of the International Search Report (PCT/ISA/210).

Items 13 to 20 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
20. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
21. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
22. ☐ Certificate of Mailing by Express Mail
23. ☒ Other items or information:

Notice of Priority / PCT/IB/304 / PCT/IB/308
Drawings (3 sheets) / Amended Sheets (page 12)
PTO-1449

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR)	INTERNATIONAL APPLICATION NO.	ATTORNEY'S DOCKET NUMBER
10/069517	PCT/FR00/02468	220040US2PCT

24. The following fees are submitted:.

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

		CALCULATIONS PTO USE ONLY
☐	Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO	**$1040.00**
☒	International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO	**$890.00**
☐	International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO	**$740.00**
☐	International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4)	**$710.00**
☐	International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4)	**$100.00**

ENTER APPROPRIATE BASIC FEE AMOUNT =	**$890.00**	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).	**$0.00**	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	10 - 20 =	0	x $18.00	**$0.00**	
Independent claims	1 - 3 =	0	x $84.00	**$0.00**	
Multiple Dependent Claims **(check if applicable)**.			☐	**$0.00**	
TOTAL OF ABOVE CALCULATIONS =				**$890.00**	
☐ Applicant claims small entity status. See 37 CFR 1.27). The fees indicated above are reduced by 1/2.				**$0.00**	
SUBTOTAL =				**$890.00**	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)). +				**$0.00**	
TOTAL NATIONAL FEE =				**$890.00**	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).** ☐				**$0.00**	
TOTAL FEES ENCLOSED =				**$890.00**	
				Amount to be: refunded	$
				charged	$

a. ☒ A check in the amount of **$890.00** to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. _____ in the amount of _____ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. **15-0030** A duplicate copy of this sheet is enclosed.

d. ☐ Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

22850

(703) 413-3000

Surinder Sachar
Registration No. 34,423

Surinder Sachar
SIGNATURE

Marvin J. Spivak
NAME

24,913
REGISTRATION NUMBER

March 5 2002
DATE

FORM PTO-1390 (Modified) (REV 11-2000) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

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PCT/FR00/02468	**07 SEPTEMBER 2000**	**08 SEPTEMBER 1999**

TITLE OF INVENTION

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APPLICANT(S) FOR DO/EO/US

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Drawings (3 sheets) / Amended Sheets (page 12)
PTO-1449

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR)	INTERNATIONAL APPLICATION NO.	ATTORNEY'S DOCKET NUMBER
10/069517	PCT/FR00/02468	220040US2PCT

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Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).	**$0.00**

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE	
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Independent claims	1 - 3 =	0	x $84.00	**$0.00**
Multiple Dependent Claims **(check if applicable).**			☐	**$0.00**

TOTAL OF ABOVE CALCULATIONS =	**$890.00**
☐ Applicant claims small entity status. See 37 CFR 1.27). The fees indicated above are reduced by 1/2.	**$0.00**
SUBTOTAL =	**$890.00**
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)). +	**$0.00**
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SEND ALL CORRESPONDENCE TO:

22850

(703) 413-3000

Surinder Sachar
Registration No. 34,423

Surinder Sachar
SIGNATURE

Marvin J. Spivak
NAME

24,913
REGISTRATION NUMBER

March 5 2002
DATE

Docket No. 220040US2PCT

IN RE APPLICATION OF: Claude JAUSSAUD, et al.

SERIAL NO: NEW U.S. PCT APPLICATION BASED ON PCT/FR00/02468

FILED: HEREWITH

FOR: CREATION OF AN ELECTRICALLY CONDUCTING BONDING BETWEEN TWO SEMI-CONDUCTOR ELEMENTS

ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, D.C. 20231

SIR:

Transmitted herewith is an amendment in the above-identified application.

☒ No additional fee is required

☐ Small entity status of this application under 37 C.F.R. §1.9 and §1.27 is claimed.

☒ Additional documents filed herewith: English Translation of Specification/Declaration/Request for Priority/PCT/IB/304
PCT/IB/308/Preliminary Amendment/PCT Transmittal Letter/Drawings (3 sheets)
International Search Report/Information Disclosure Statement/PTO-1449
Amended Sheets (page 12)/Check for $890.00

The Fee has been calculated as shown below:

CLAIMS	CLAIMS REMAINING		HIGHEST NUMBER PREVIOUSLY PAID	NO. EXTRA CLAIMS	RATE	CALCULATIONS
TOTAL	10	MINUS	20	0	× $18 =	$0.00
INDEPENDENT	1	MINUS	3	0	× $84 =	$0.00
		☐ MULTIPLE DEPENDENT CLAIMS			+ $280 =	$0.00
		TOTAL OF ABOVE CALCULATIONS				$0.00
		☐ Reduction by 50% for filing by Small Entity				$0.00
		☐ Recordation of Assignment			+ $40 =	$0.00
					TOTAL	$0.00

☐ A check in the amount of **$0.00** is attached.

☒ Please charge any additional Fees for the papers being filed herewith and for which no check is enclosed herewith, or credit any overpayment to deposit Account No. 15-0030. A duplicate copy of this sheet is enclosed.

☒ If these papers are not considered timely filed by the Patent and Trademark Office, then a petition is hereby made under 37 C.F.R. §1.136, and any additional fees required under 37 C.F.R. §1.136 for any necessary extension of time may be charged to Deposit Account No. 15-0030. A duplicate copy of this sheet is enclosed.

OBLON, SPIVAK, McCLELLAND,
MAIER & NEUSTADT, P.C.

Marvin J. Spivak
Registration No. 24,913

Surinder Sachar
Registration No. 34,423

22850
Customer Number 22850
Tel. (703) 413-3000
Fax. (703) 413-2220
(OSMMN 10/01)

Docket No. 220040US2PCT

IN RE APPLICATION OF: Claude JAUSSAUD, et al.

SERIAL NO: NEW U.S. PCT APPLICATION BASED ON PCT/FR00/02468

FILED: HEREWITH

FOR: CREATION OF AN ELECTRICALLY CONDUCTING BONDING BETWEEN TWO SEMI-CONDUCTOR ELEMENTS

ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, D.C. 20231

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Transmitted herewith is an amendment in the above-identified application.

☒ No additional fee is required

☐ Small entity status of this application under 37 C.F.R. §1.9 and §1.27 is claimed.

☒ Additional documents filed herewith: English Translation of Specification/Declaration/Request for Priority/PCT/IB/304
PCT/IB/308/Preliminary Amendment/PCT Transmittal Letter/Drawings (3 sheets)
International Search Report/Information Disclosure Statement/PTO-1449
Amended Sheets (page 12)/Check for $890.00

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OBLON, SPIVAK, McCLELLAND,
MAIER & NEUSTADT, P.C.

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Registration No. 24,913

Surinder Sachar
Registration No. 34,423

22850
Customer Number 22850
Tel. (703) 413-3000
Fax. (703) 413-2220
(OSMMN 10/01)

220040US-902-236424-2-PCT

IN THE UNITED STATES PATENT & TRADEMARK OFFICE

IN RE APPLICATION OF :

CLAUDE JAUSSAUD ET AL. : ATTN: APPLICATION DIVISION

SERIAL NO: NEW U.S. PCT APPLN :
(Based on PCT/FR00/02468)

FILED: HEREWITH :

FOR: CREATION OF AN ELECTRICALLY:
CONDUCTING BONDING BETWEEN
TWO SEMI-CONDUCTOR ELEMENTS

PRELIMINARY AMENDMENT

ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, D.C. 20231

SIR:

Prior to a first examination on the merits, please amend the above-identified application as follows:

IN THE CLAIMS

Please cancel Claims 1-10 without prejudice.

Please add new Claims 11-20 as follows:

11. (New) Method of creating an electrically conducting bonding between a face of a first semiconductor element and a face of a second semiconductor element by heat treatment, comprising:

depositing at least one layer of material on said face of the first semiconductor element and at least one layer of material on said face of the second semiconductor element,

these deposited layers combining during said heat treatment to form a layer that provides an electrically conducting bonding between the two faces,

applying said faces one against the other, with interposing of said layers of deposited material; and

carrying out a heat treatment;

wherein the layer of material deposited onto said face of the first semiconductor element and the layer of material deposited onto said face of the second semiconductor element are chosen to react in a solid phase during the heat treatment and to form a temperature stable mixture with respect to the first and the second semiconductor elements, the heat treatment not inducing any reaction product between the deposited materials and at least one of the semiconductor elements.

12. (New) Method according to Claim 11, wherein during a preliminary step, a thin film is bounded in a substrate by a layer of microcavities obtained by ionic implantation, the second semiconductor element, the heat treatment forming a mixture that does not induce any reaction product with the first and the second semiconductor elements.

13. (New) Method according to Claim 11, wherein one of the layers of material is deposited with an excess thickness such that a part of this layer, in contact with the other layer of material, combines with the other deposited layer of material to form said stable mixture, the other part of the layer deposited with an excess thickness, in contact with the semiconductor element on which it is deposited, reacting during the heat treatment with this semiconductor element to form a film with ohmic contact.

14. (New) Method according to Claim 11, wherein a layer of oxide is provided between said deposited layers of material, the oxide being chosen to react with at least one material of said deposited layers, thicknesses of the oxide layer and the layer of material with

which the oxide reacts being such that the oxide formed is in a form of isolated precipitates that do not substantially harm the electrically conducting bonding.

15. (New) Method according to Claim 14, wherein said layer of oxide is deposited on one of the deposited layers of material or on both of them.

16. (New) Method according to Claim 11, wherein the first and second semiconductor elements are pressed one against the other during the heat treatment.

17. (New) Method according to Claim 11, wherein the first semiconductor element is SiC and the second semiconductor element is SiC, the interposed layers comprising a layer of tungsten and a layer of silicon on said face of the first semiconductor element and a layer of tungsten and a layer of silicon on said face of the second semiconductor element, the mixture formed after the heat treatment comprising WSi_2.

18. (New) Method according to Claim 11, wherein one of the semiconductor elements is a thin film, and the method comprises a preliminary step of defining this thin film as a superficial layer of a substrate, configured to be separated from a rest of the substrate.

19. (New) Method according to Claim 18, wherein during the preliminary step the substrate is formed by stacking a support, a sacrificial layer, and the thin film, separation of the thin film from the rest of the substrate being obtained after creation of the bonding, by dissolution of the sacrificial layer.

20. (New) Method according to Claim 18, wherein during the preliminary step the thin film is bounded in a substrate by a layer of microcavities obtained by ionic implantation, the separation of the thin film from the rest of the substrate being consecutive to the bonding heat treatment or to a specific heat treatment or to the application of mechanical forces or to the combination of a heat treatment and the application of mechanical forces.

IN THE ABSTRACT

Please cancel the original Abstract on page 16 in its entirety and insert therefor:

ABSTRACT

A method of creating an electrically conducting bonding between a face of a first semiconductor element and a face of a second semiconductor element using heat treatment. The method applies the faces one against the other with the placing between them of at least one layer of a material configured to provide, after heat treatment, an electrically conducting bonding between the two faces. The deposited layers are chosen so that the heat treatment does not induce any reaction product between said material and the semi-conductor elements. Then, a heat treatment is carried out.

REMARKS

Favorable consideration of this application, as presently amended, is respectfully requested.

The present Preliminary Amendment is submitted to place the above-identified application in more proper format under United States practice.

By the present Preliminary Amendment original Claims 1-10 are cancelled and new Claims 11-20 are presented for examination. New Claims 11-20 are deemed to be self-evident from the original disclosure, including original Claims 1-10, and thus are not deemed to raise any issues of new matter.

Further, new Claims 11-20 are not believed to be more narrow in scope in any aspect than original Claims 1-10. Certain aspects of new Claims 11-20 are in fact broader. For example, new independent Claim 11 does not recite the term "consisting of" and instead recites the broader term "comprising".

A new Abstract believed to be in more proper format under United States practice is also submitted herein.

The present application is believed to be in condition for a full and thorough examination on the merits. An early and favorable consideration of the present application is hereby respectfully requested.

Respectfully submitted,

OBLON, SPIVAK, McCLELLAND,
MAIER & NEUSTADT, P.C.

Gregory J. Maier
Attorney of Record
Registration No. 25,599
Surinder Sachar
Registration No. 34,423

22850
Tel.: (703) 413-3000
Fax: (703) 413-2220
GJM:SNS\la
I:\atty\SNS\220040us-pr.wpd

Marked-Up Copy
Serial No:

Amendment Filed on:
3-5-2002

IN THE CLAIMS

Claims 1-10 (Cancelled).

Claims 11-20 (New).

IN THE ABSTRACT

Abstract (New).

English translation of the amended sheet of
International Preliminary Examination Report

CLAIMS

1. Method of creating an electrically conducting bonding between a face of a first semi-conductor element (10, 32, 55) and a face of a second semi-conductor element (12, 34, 53) by means of heat treatment, consisting of:

- depositing at least one layer of material on said face of the first semi-conductor element and at least one layer of material on said face of the second semi-conductor element, these deposited layers combining during said heat treatment to form a layer that provides an electrically conducting bonding between the two faces,

- applying said faces one against the other, interposing said layers of deposited material,

- carrying out said heat treatment, characterized in that the layer of material (11, 15, 33, 37, 52, 57) deposited on said face of the first semi-conductor element and the layer of material (13, 16, 35, 38, 54, 58) deposited on said face of the second semi-conductor element are chosen in order to react in solid phase during the heat treatment and to form a mixture that is stable for a temperature higher than the heat treatment temperature for the first (10, 32, 55) and for the second (12, 34, 53) semi-conductor element respectively, the heat treatment not inducing any reaction product between the deposited materials and at least one of the semi-conductor elements.

2. Method according to Claim 1, characterized in that during the preliminary step, the thin film is bounded in a substrate (50) by a layer of micro-cavities (51) obtained by ionic implantation, the

CREATION OF AN ELECTRICALLY CONDUCTING BONDING BETWEEN TWO SEMI-CONDUCTOR ELEMENTS

Technical field

This invention relates to a method that permits the creation of an electrically conducting bonding between two semi-conductor elements.

State of the prior art

The transfer of a thin film of semi-conductor material onto a support is often used in the field of micro-electronics. This is the case particularly for devices produced on GaAs for which it is preferable to lay a substrate made up of a thin film of GaAs on a silicon support. This solution offers several advantages. It enables one to reduce the costs since GaAs is an expensive material in relation to silicon. It enables one to simplify handling since GaAs is fragile and therefore must be handled delicately. It also enables one to reduce the weight of the components, which is an important parameter for space applications, since silicon is lighter than GaAs.

Such a transfer is made traditionally by bonding using an oxide, this type of bonding being easy to control. However, bonding using an oxide has the particular feature that the thin film is electrically insulated from its support. Hence, for certain applications it is necessary to establish vertical electrical conduction through the substrate. This is the case particularly for diodes produced on a film of SiC formed on a silicon support and for solar cells produced by deposition of GaAs on silicon.

Furthermore, certain types of transistors (for example, transistors with a permeable base or a metal base) necessitate having a metal layer buried under the layer of semi-conductor from which they are produced. This type of layer is difficult to create and conductive bonding is the most simple way of producing this type of structure.

Several solutions have been proposed for creating conducting bonding of two plates of silicon. One may mention the article "Buried Cobalt Silicide Layers in Silicon Created by Wafer Bonding" by K. LJUNGBERG et al., that appeared in J. Electrochem. Soc., Vol. 141, No. 10, October 1994, pages 2829-2833 and the article "Low Temperature Silicon Wafer to Wafer Bonding with Nickel Silicide" by Zhi Xiong Xiao et al., that appeared in J. Electrochem. Soc., Vol. 145, No. 4, April 1998, pages 1360-1362. All these solutions consist of forming a silicide from a metal deposited on the faces of the plates to be bonded, by reaction of the metal and the semi-conductor material. These solutions have two disadvantages. On the one hand, the formation of the silicide consumes a part of the semi-conductor film which may be a disadvantage in the case of very thin films. On the other hand, there is diffusion of the metal into the semi-conductor, which has the consequence of degrading its properties. This is particularly the case if nickel is used. Furthermore, the compounds formed are not stable at high temperature which restricts the possibilities for heat treatment after creation of the bonding. These two things can be very important, if one wishes, after bonding to carry out an epitaxy which can involve the

use of high temperatures (of the order of 1600°C in the case of SiC).

Description of the invention

So as to remedy the disadvantages mentioned above, according to this invention, it is proposed to use a bonding that uses one or more layers that do not react with at least one of the two semi-conductor materials to be electrically connected.

Therefore the subject of the invention is a method for creating an electrically conducting bonding between a face of a first semi-conductor element and a face of a second semi-conductor element by means of heat treatment, consisting of :

- depositing at least one layer of material on said face of the first semi-conductor element and at least one layer of material on said face of the second semi-conductor element, these deposited layers combining during said heat treatment to form a layer that provides an electrically conducting bonding between the two faces,

- applying said faces one against the other, with interposing of said layers of deposited material between them,

- carrying out said heat treatment, characterized in that the layer of material deposited onto said face of the first semi-conductor element and the layer of material deposited onto said face of the second semi-conductor element are chosen in order to react in the solid phase during the heat treatment and to form a temperature stable mixture with respect to the first and the second semi-conductor element, the heat treatment not inducing any reaction product between the

deposited materials and at least one of the semi-conductor elements.

According to one particular embodiment, the material of the layer deposited on the face of the first semi-conductor element is distinct from the material of the layer deposited on the face of the second semi-conductor element, the heat treatment forming a mixture that does not induce any reaction product with the first and the second semi-conductor.

According to another particular embodiment, one of the layers of material is deposited with an excess thickness such that a part of this layer, in contact with the other layer of material combines with the other deposited layer of material in order to form said stable mixture, the other part of the layer deposited with an excess thickness, in contact with the semi-conductor element on which it is deposited, reacting during the heat treatment with this semi-conductor element in order to form a film with ohmic contact.

A layer of oxide may be provided between the deposited layers of material, the oxide being chosen in order to react with at least one material of said deposited layers, the thicknesses of the oxide layer and the layer of material with which the oxide reacts being such that the oxide formed is in the form of isolated precipitates which do not substantially harm the electrically conducting bonding. This layer of oxide may be deposited on one of the layers of material or on both of them, for example, by a method chosen from among vacuum deposition and sol-gel type deposition.

In order to improve the bonding, the first and second semi-conductor elements can be pressed one against the other during the heat treatment.

The electrically conducting bonding may result from a mixture of identical materials. By way of an example, the first semi-conductor element is SiC and the second semi-conductor element is SiC, the intermediate layers comprising a layer of tungsten and a layer of silicon on said face of the first semi-conductor element and a layer of tungsten and a layer of silicon on said face of the second semi-conductor element, the mixture formed after the heat treatment comprising WSi_2.

If one of the semi-conductor elements is a thin film, the method may comprise a preliminary step consisting of defining this thin film as a superficial layer of a substrate, intended to be separated from the rest of the substrate. According to a first embodiment example, during the preliminary step, the substrate is formed by stacking a support, a sacrificial layer and the thin film, the separation of the thin film from the rest of the substrate being obtained, after creation of the bonding, by dissolution of the sacrificial layer. According to a second embodiment example, during the preliminary step, the thin film is bounded in a substrate by a layer of micro-cavities obtained by ionic implantation, the separation of the thin film from the rest of the substrate being consecutive to the bonding heat treatment or to a specific heat treatment or to the application of mechanical forces or to the combination of a heat treatment and the application of mechanical forces.

Brief description of the drawings

The invention will be better understood and other advantages and particular features will become apparent on reading the description that follows, given by way of a non-limitative example and accompanied by the appended drawings among which :

- Figures 1A to 1D illustrate a first example of the creation of an electrically conducting bonding between two semi-conductor elements, according to the method of the invention,

- Figures 2A to 2E illustrate a second example of the creation of an electrically conducting bonding between two semi-conductor elements, according to the method of the invention,

- Figures 3A to 3D illustrate a third example of the creation of an electrically conducting bonding between two semi-conductor elements, according to the method of the invention.

Detailed description of embodiments of the invention

The invention proposes the creation of a bonding using layers which do not react with one or the other of the semi-conductor elements to be electrically connected.

According to the invention, the materials interposed between the two elements to be bonded react during the heat treatment to form a mixture stable with respect to these elements at high temperatures and notably temperatures greater than that of the heat treatment. This stability at high temperature is particularly important when the elements are made of SiC and one of them must be subjected to epitaxy.

The method according to the invention does not require the use of a diffusion barrier although a diffusion barrier may be used.

Preferably, the interposed materials are :

- W (or a compound based on W)/Si
- W (or a compound based on W)/Si/W (or a compound based on W).

The thicknesses of the interposed layers are generally dimensioned so that all of the materials in these layers interact to form a new stable material. However, in certain cases, it may be advantageous to use at least one layer of material having an excess thickness. This excess thickness of material then reacts during the high temperature heat treatment with the element with which it is in contact in order to form a film with ohmic contact.

By way of example, for elements to be bonded made of SiC and interposed layers made of W and Si, in order for all of the interposed layers to react, the ratio of the total thickness of the Si layer or layers to the total thickness of the W layer or layers must be equal to or close to 2.5 in order to obtain a homogeneous layer of WSi_2. In order to have an excess thickness capable of reacting, it must be slightly below 2.5. This enables one to have a thin film based on WSi and WC which is also stable at high temperature.

According to a kinetic approach, layers are used which are only thermodynamically stable with one or the other of the semi-conductor materials at the temperatures used during production of the devices and during their use, after the heat treatment for bonding the two semi-conductor elements. For example, in the case of the transfer of silicon carbide onto silicon

carbide, the following stacks can be used : SiC element/W layer/Si layer-Si layer/W layer/SiC, the silicon being amorphous or crystalline. During the heat treatment, the tungsten reacts with the silicon to form WSi_2. For a structure SiC/W (thickness 0.1 µm)/Si (thickness 0.25 µm)-Si(thickness 0.25 µm)/W (thickness 0.1 µm)/SiC, SiC/WSi_2/SiC is obtained. Reaction occurs from 650°C, implying reaction of the silicon with the tungsten, without the thin film of SiC being consumed and the system is stable at more than 1600°C.

Figures 1A to 1D are transverse views which illustrate a first embodiment example of the method according to the invention for which the bonding is carried out in accordance with a kinetic approach. Figure 1A shows a SiC plate 10 covered successively with a layer 11 of tungsten and a layer 15 of silicon. Figure 1B shows a SiC plate 12 covered successively with a layer 13 of tungsten and a layer 16 of silicon. Figure 1C shows the joining of the structures shown in Figures 1A and 1B, theses structures being brought into contact through their layers 15 and 16. After heat treatment from 650°C, the assembly shown in Figure 1D is obtained. The SiC plate 10 is connected by an electrically conducting bonding to the SiC plate 12 thanks to the intermediate layer 14 formed between the two plates and comprising WSi_2.

Such an electrically conducting bonding can be used to bond a thin semi-conductor film onto a semi-conductor support. So as to obtain this thin film, the thickness of one of the two bonded plates may be reduced. This has two major disadvantages. On the one hand, it is difficult to obtain a thin film homogeneous

throughout its thickness and, on the other hand, there is a loss from the rest of the semi-conductor plate supplying this film. This invention also enables one to remedy these disadvantages. A first solution makes use of a sacrificial layer. A second solution employs a cleavage method after ionic implantation.

Figures 2A to 2E are transverse views which illustrate the creation of an electrically conducting bonding, in accordance with a kinetic approach, between a semi-conductive SiC plate and a thin SiC film obtained by dissolution of a sacrificial layer. Figure 2A shows a silicon plate 30 covered with a layer 31 of silicon oxide or silicon nitride which will be used as a sacrificial layer. The sacrificial layer 31 is covered successively with a SiC layer 32, which will provide the thin film, a layer 33 of tungsten and a layer 37 of silicon. Figure 2B shows a SiC plate 34 covered with a layer 35 of tungsten and a layer 38 of silicon. Figure 2C shows the joining of the structures shown in Figures 2A and 2B, these structures being brought into contact through their layers 37 and 38. After heat treatment from 650°C, the assembly shown in Figure 2D is obtained. The SiC layer 32 is connected through an electrically conducting bonding to the SiC plate 34 thanks to the intermediate layer 36 constituted by WSi_2. The sacrificial layer is then dissolved by a technique known to a man skilled in the art. On obtains, on the one hand, the structure shown in Figure 2E, that is to say a thin film of SiC bonded through an electrical connection to a SiC support, and on the other hand, a reusable silicon plate.

Figures 3A to 3D are transverse views which illustrate the creation of an electrically conducting

bonding, in accordance with a kinetic approach, between a semi-conductive SiC plate and a thin SiC film obtained by cleavage after ionic implantation. Figure 3A shows a SiC plate 50 within which a layer 51 of micro-cavities has been generated by ionic implantation, through one of the faces of the plate 50, in accordance with the technique disclosed by the document FR-A-2 681 472. A layer 52 of tungsten and a layer 57 of silicon have been successively deposited on the implanted face of the plate 50. Figure 3B shows a plate 53 of SiC covered with a layer 54 of tungsten and a layer 58 of silicon. Figure 3C shows the joining of the structures shown in Figures 3A and 3B, these structures being brought into contact through their layers 57 and 58. After heat treatment, the assembly shown in Figure 3D is obtained. The heat treatment causes cleavage of the plate 50 along the layer of micro-cavities. A thin film 55 of SiC remains, which is connected by an electrically conducting bonding to the SiC plate 53 thanks to the intermediate layer 56 comprising WSi_2. The remainder of the plate 50 can then be reused.

In an advantageous way, so as to improve the bonding, pressure can be applied between the assembled structures. One may also, conjointly or not, use a thin layer of oxide on the surface of at least one of the structures in order to reduce the pressure necessary for the bonding, or indeed do without it. This layer of oxide must be sufficiently fine (a few Angströms) and capable of interacting with at least one of the bonding materials to form, at the end of the process, precipitates which do not hinder the electrical conduction. During the heat treatment, the thin layer

of oxide reacts with the metal which is offered to it, if the metal is sufficiently electropositive, to form metal oxides which are in the form of isolated precipitates. In particular, this is the case with titanium which reacts with the oxide SiO_2 to form TiO_2 and releasing silicon. Hence a stack SiC/SiO_2 (of thickness 0.01 μm)-SiO_2 (of thickness 0.01 μm)/Ti (of thickness 0.1 μm)/Si provides the structure $SiC/(TiSi_2 + TiO_x)/Si$. The reaction occurs at 1000°C, implying reaction of the silicon with the titanium and reduction of the SiO_2 by the titanium, without the thin film of SiC being consumed. The SiO_2 must be thin so that the TiO_2 does not form a continuous layer. The system is stable up to 1330°C (limited by the formation of a eutectic between $TiSi_2$ and Si at this temperature).

The description above can be applied to the bonding of other elements. Hence, for example, one may bond a layer of GaN epitaxiated on a substrate of sapphire or SiC with a SiC substrate by interposing at least two layers of materials, respectively W and Si.

CLAIMS

1. Method of creating an electrically conducting bonding between a face of a first semi-conductor element (10, 32, 55) and a face of a second semi-conductor element (12, 34, 53) by means of heat treatment, consisting of :

- depositing at least one layer of material on said face of the first semi-conductor element and at least one layer of material on said face of the second semi-conductor element, these deposited layers combining during said heat treatment to form a layer that provides an electrically conducting bonding between the two faces,

- applying said faces one against the other, with interposing of said layers of deposited material,

- carrying out said heat treatment, characterized in that the layer of material (11, 15, 33, 37, 52, 57) deposited onto said face of the first semi-conductor element and the layer of material (13, 16, 35, 38, 54, 58) deposited onto said face of the second semi-conductor element are chosen in order to react in the solid phase during the heat treatment and to form a temperature stable mixture with respect to the first (10, 32, 55) and the second (12, 34, 53) semi-conductor element, the heat treatment not inducing any reaction product between the deposited materials and at least one of the semi-conductor elements.

2. Method according to Claim 1, characterized in that the material of the layer deposited on the face of the first semi-conductor element is distinct from the material of the layer deposited on the face of the

second semi-conductor element, the heat treatment forming a mixture that does not induce any reaction product with the first and the second semi-conductor element.

3. Method according to one of Claims 1 or 2, characterized in that one of the layers of material is deposited with an excess thickness such that a part of this layer, in contact with the other layer of material combines with the other deposited layer of material in order to form said stable mixture, the other part of the layer deposited with an excess thickness, in contact with the semi-conductor element on which it is deposited, reacting during the heat treatment with this semi-conductor element in order to form a film with ohmic contact.

4. Method according to Claim 1, characterized in that a layer of oxide is provided between said deposited layers of material, the oxide being chosen in order to react with at least one material of said deposited layers, the thicknesses of the oxide layer and the layer of material with which the oxide reacts being such that the oxide formed is in the form of isolated precipitates which do not substantially harm the electrically conducting bonding.

5. Method according to Claim 4, characterized in that said layer of oxide is deposited on one of the deposited layers of material or on both of them.

6. Method according to Claim 1, characterized in that the first and second semi-conductor elements are

pressed one against the other during the heat treatment.

7. Method according to Claim 1, characterized in that the first semi-conductor element is SiC and the second semi-conductor element is SiC, the interposed layers comprising a layer of tungsten and a layer of silicon on said face of the first semi-conductor element and a layer of tungsten and a layer of silicon on said face of the second semi-conductor element, the mixture formed after the heat treatment comprising WSi_2.

8. Method according to any one of the preceding Claims, characterized in that, one of the semi-conductor elements being a thin film (32, 55), the method comprises a preliminary step consisting of defining this thin film as a superficial layer of a substrate, intended to be separated from the rest of the substrate.

9. Method according to Claim 8, characterized in that during the preliminary step, the substrate is formed by stacking a support (30), a sacrificial layer (31) and the thin film (32), the separation of the thin film from the rest of the substrate being obtained after creation of the bonding, by dissolution of the sacrificial layer (31).

10. Method according to Claim 8, characterized in that during the preliminary step, the thin film is bounded in a substrate (50) by a layer of micro-cavities (51) obtained by ionic implantation, the

separation of the thin film from the rest of the substrate being consecutive to the bonding heat treatment or to a specific heat treatment or to the application of mechanical forces or to the combination of a heat treatment and the application of mechanical forces.

ABSTRACT OF THE DISCLOSURE

This invention relates to a method of creating an electrically conducting bonding between a face of a first semi-conductor element (10) and a face of a second semi-conductor element (12) using heat treatment. The method consists of :

- applying said faces one against the other with the placing between them of at least one layer (11, 15, 16, 13) of a material intended to provide, after heat treatment, an electrically conducting bonding between the two faces, the deposited layers being chosen so that the heat treatment does not induce any reaction product between said material and the semi-conductor elements (10, 12),

- carrying out said heat treatment.

Fig. 1C

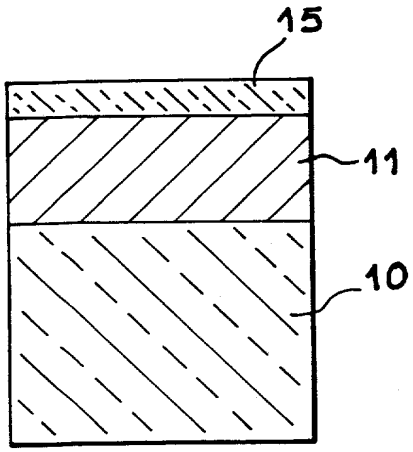

FIG. 1A

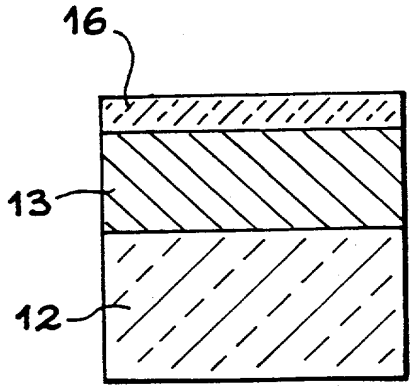

FIG. 1B

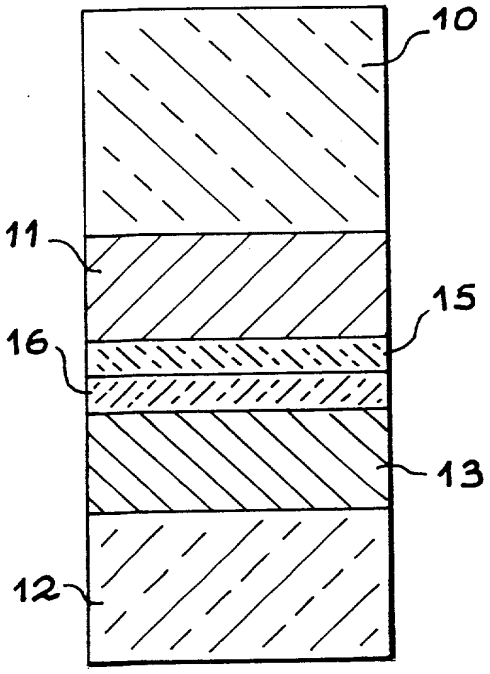

FIG. 1C

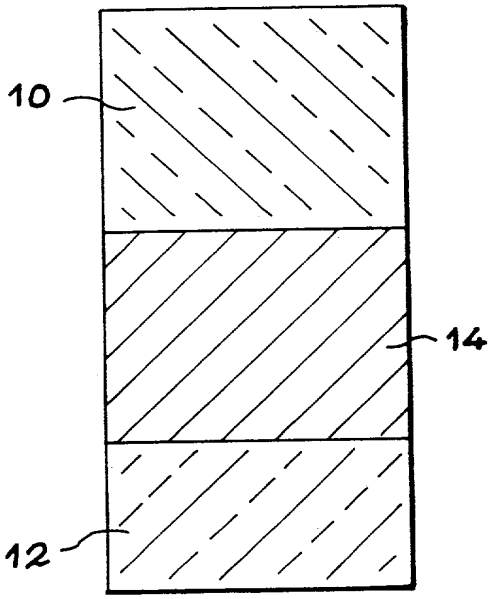

FIG. 1D

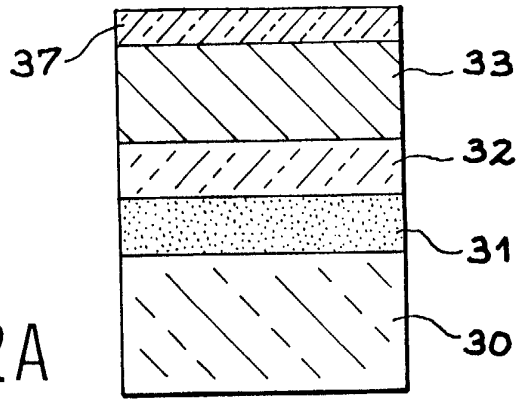

FIG. 2A

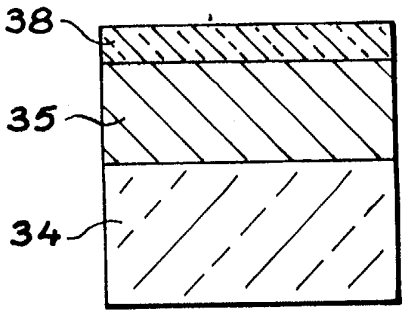

FIG. 2B

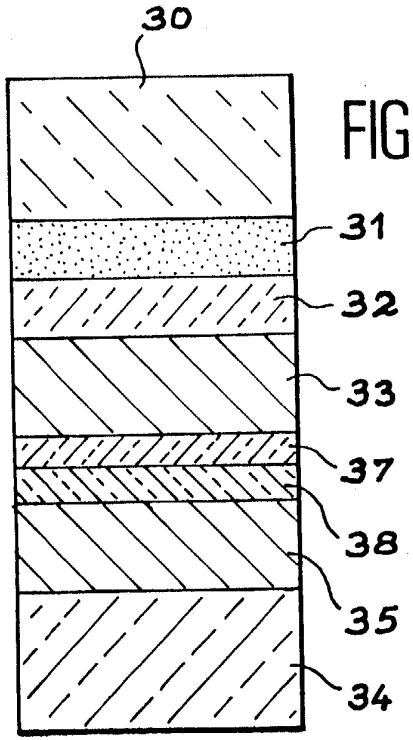

FIG. 2C

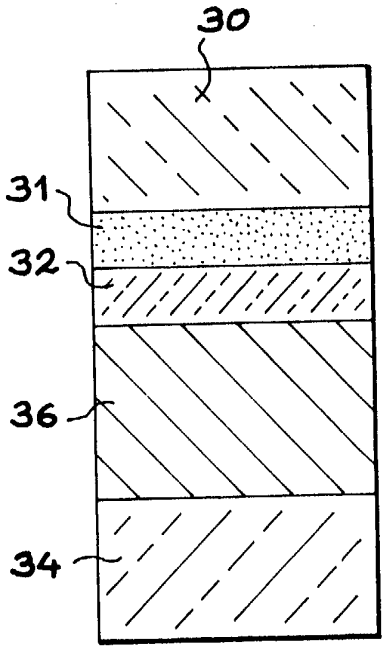

FIG. 2D

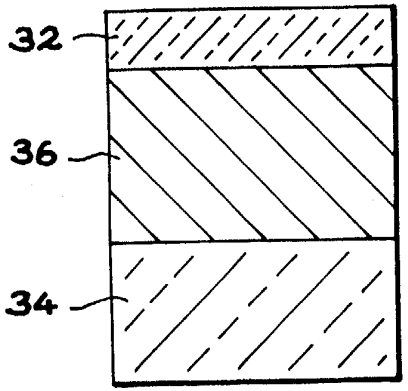

FIG. 2E

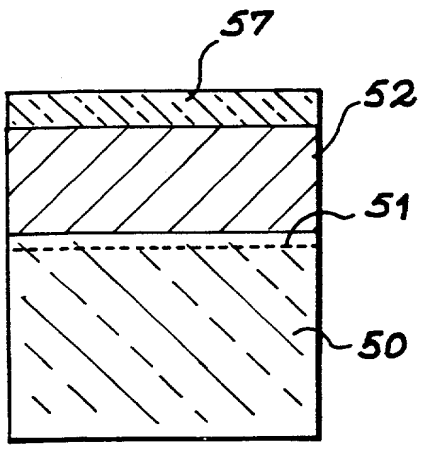

FIG. 3A

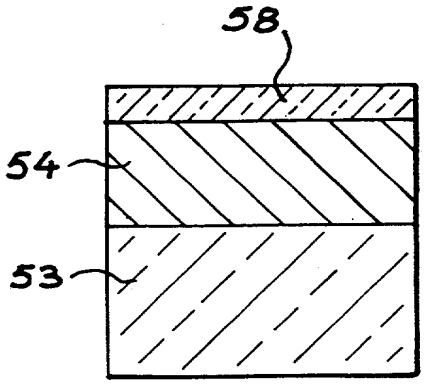

FIG. 3B

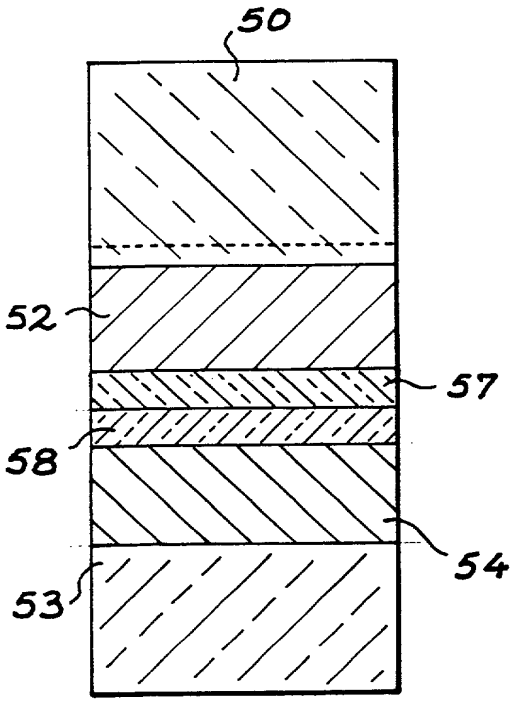

FIG. 3C

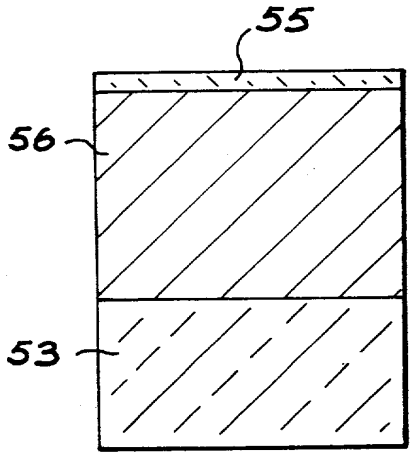

FIG. 3D

B 13188.3 JL

Declaration, Power Of Attorney and Petition

WE (I) the undersigned inventor(s), hereby declare(s) that :

My residence, post office address and citizenship are as stated below next to my name,

We (I) believe that we are (I am) the original, first, and joint (sole) inventor(s) of the subject matter which is claimed and for which a patent is sought on the invention entitled

CREATION OF AN ELECTRICALLY CONDUCTING BONDING BETWEEN TWO SEMI-CONDUCTOR ELEMENTS

the specification of which

- ☐ is attached hereto.
- ☐ was filed on
  as Application Serial No.
  and amended on
- ☒ was filed as PCT international application
  Number PCT/FR00/02468
  on September 07, 2000
  and was amended under PCT Article 19
  on September 28, 2001

We (I) hereby state that we (I) have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

We (I) acknowledge the duty to disclose information known to be material to the patentability of this application as defined in Section 1.56 of Title 37 Code of Federal Regulations.

We (I) hereby claim foreign priority benefits under 35 U.S.C. § 119 (a)-(d) or § 365 (b) of any foreign application(s) for patent or inventor's certificate, or § 365 (a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed. Prior Foreign Application (s)

Application No.	Country	Day/month/Year	Priority Claimed
99 11224	FRANCE	08 SEPTEMBER 1999	☒ YES ☐ NO
			☐ YES ☐ NO
			☐ YES ☐ NO
			☐ YES ☐ NO

We (I) hereby claim the benefit under Title 35, United States Code, § 119 (e) of any United States provisional application(s) listed below.

(Application Number) (Filing Date)

(Application Number) (Filing Date)

We (I) hereby claim the benefit under 35 U.S.C. §120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of prior application and the national or PCT International filing date of this application.

Application Serial No.	Filing Date	Status (pending, patented, abandoned)

And we (I) hereby appoint : Norman F. Oblon, Registration Number 24,618; Marvin J. Spivak, Registration Number 24,913; C, Irvin McClelland, Registration Number 21,124; Gregory J. Maier, Registration Number 25,599; Arthur I. Neustadt, Registration Number 24,854; Richard D. Kelly, Registration Number 27,757; James D. Hamilton, Registration Number 28,421; Eckhard H. Kuesters, Registration Number 28,870; Robert T. Pous, Registration Number 29,099; Charles L. Gholz, Registration Number 26,395; William E. Beaumont, Registration Number 30,996; Jean-Paul Lavalleye, Registration Number 31,451; Stephen G. Baxter, Registration Number 32,884; Richard L. Treanor, Registration Number 36,379; Steven P. Weihrouch, Registration Number 32,829; John T. Goolkasian, Registration Number 26,142; Richard L. Chinn, Registration Number 34,305; Steven E. Lipman, Registration Number 30,011; Carl E. Schlier, Registration Number 34,426; James J. Kulbaski, Registration Number 34,648; Richard A. Neifeld, Registration Number 35,299; J. Derek Mason, Registration Number 35,270; Surinder Sachar, Registration Number 34,423; Christina M. Gadiano, Registration Number 37,628; Jeffrey B. McIntyre, Registration Number 36,867; William T. Enos, Registration Number 33,128; Michael E. McKabe Jr., Registration Number 37,182, Bradley D. Lytle, Registration Number 40,073 and Michael R. Casey Registration Number 40,294 ; our (my) attorneys, with full powers of substitution and revocation, to prosecute this application and to transact all business in the Patent Office connected therewith; and we (I) hereby request that all correspondence regarding this application be sent to the firm of OBLON, SPIVAK, McCLELLAND, MAIER & NEUSTADT, P.C., whose post Office Address is : Fourth Floor, 1755 Jefferson Davis Highway, Arlington, Virginia 22202.

We (I) declare that all statements made herein of our (my) own knowledge are true and that all statements made on information and belief are believed to be true ; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such wilful false statements may jeopardise the validity of the application or any patent issuing thereon.

JAUSSAUD Claude

NAME OF FIRST SOLE INVENTOR

Residence : 6 Allée des Tonnelles
38240 MEYLAN
FRANCE

Citizen of : Français

Signature of Inventor

Post Office Address : The same as residence

February 20, 2002

Date

JALAGUIER Eric

NAME OF SECOND INVENTOR

Signature of Inventor

February 20, 2002
Date

Residence : 205 Chemin des Roux
Le Penet 38440 Saint Martin d'Uriage
FRANCE

Citizen of : Française FRX

Post Office Address : The same as residence

MADAR Roland

NAME OF THIRD INVENTOR

L. Madar
Signature of Inventor

February 20, 2002
Date

Residence : 11 Allée des Bruelles
38320 Eybens. France FRX

Citizen of : Française

Post Office Address : The same as residence

NAME OF FOURTH INVENTOR

Signature of Inventor

Date

Residence :

Citizen of :

Post Office Address : The same as residence

NAME OF FIFTH INVENTOR

Signature of Inventor

Date

Residence :

Citizen of :

Post Office Address : The same as residence